Ostwald Ripening of Liquid and Solid "Droplets" in Liquid Metal Matrices

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The purpose of this research is to investigate the influence of volume fraction, f, on the kinetics of Ostwald ripening (coarsening) of liquid or solid "droplets" in a liquid metal matrix, and to compare the data with the predictions of existing theories. This objective will be attained by continuously monitoring the variation of electrical resistivity, , of the liquid matrix caused by the depletion of solute of concentration, X, that inevitably accompanies the growth of the droplets. Theoretical estimates indicate that the expected changes in X during coarsening will be in the range of parts per million, hence the expected changes in will be in the neighborhood of 10^{-3} to $10^{-2}~n~$ m (1 n $\,$ m = $0.1~\mu~$ cm), which are very small but hypothetically measurable. Furthermore, calculations of for two-phase mixtures show that when f is small (0.05~or less) all changes in $\,$ can be attributed to changes in X, since the contribution of the dispersed droplets to $\,$ is negligible. Measurements of particle sizes and size distributions, and the attendant difficulties of quenching of the alloys from the liquid state and uncertainties associated with preservation of the liquid state "microstructure," are avoided. Microgravity is essential for successfully conducting the proposed experiments because differences between the mass densities of the matrix and droplet phases induce particle motion due to gravity-driven sedimentation forces.

Several major experimental difficulties were anticipated at the outset. One was from temperature fluctuations associated with conventional temperature control. This creates a problem because the change in resistivity with temperature, / T, can far exceed that from changes in concentration, / X. Another was from temperature gradients, which stimulate Marangoni motion when liquid droplets are dispersed phase. We believe that both of these difficulties have been overcome through the design of a novel furnace, described below. A third difficulty is associated with measuring the very small changes in X, hence , during coarsening. This requires highly sensitive circuitry, and a bridge circuit for contactless measurement of was proposed; it involves measurements of the change in inductance of mutual inductance coils. It was intended that the twophase system be configured so that one of the two inductors contained an "active" specimen and the other a "dummy" specimen maintained at exactly the same temperature. The dummy specimen should be a liquid solution held at the experimental coarsening temperature, so that its composition is constant as a function of aging time. The output of the bridge circuit would therefore be expected to depend only on the difference in concentration between the actual and dummy specimens, and would be essentially unaffected by temperature fluctuations since both the actual and dummy specimens would always be at exactly the same temperature. Calculations show that the skin depths of a candidate Zn-Pb alloy are 2.25 mm at a frequency of 10 kHz and 1.60 mm at 20 kHz, indicating that there are no special dimensional limitations to the sizes of the specimens contained in the bridge circuit.

The major positive progress to date is the successful design and construction of a novel furnace consisting of heating elements placed in the interior of a water-cooled jacket. The jacket is constructed from concentric quartz tubes, 450 mm long, and configured so that water flows in the 6 mm wide channel between them. The outer diameter of the larger outer tube is 18 mm, while the inner diameter of the smaller inner tube is 10 mm. The heating element is nichrome wire 0.32 mm in diameter, insulated using Al₂O₃ tubes 0.8 mm in outer diameter and attached to another quartz tube with an inner diameter of 3 mm; it is this tube that is intended to contain the specimen during an experiment. The continuous wire strand is parallel to the axes of the water-cooled tubes, and the entire assembly fits comfortably inside the inner water-cooled tube. The method of "winding" used is non-inductive and eliminates local variations in spacing using a helical winding configuration, which earlier experiments indicated produced non-reproducible and essentially uncontrollable temperature gradients along the length of the furnace. However, the temperature gradients are extremely sensitive to the geometry of the insulation used between the heating elements and the inner water-cooled tube. By trial and error, the gradients have been reduced so that the maximum variation along a length of approximately 200 mm does not exceed ±0.5 °C when the average temperature inside the furnace is between 510 and 550 °C. Attaining this temperature requires a power input of only ~225 Watts (150 V DC at ~1.5 A). Temperature measurements over a period of 6 h indicate a temperature fluctuation of only ± 0.5 °C using a Sorensen DCR-B 300-9B power supply with voltage stability of 0.1% for 8 h after warming up for 30 min. We believe that this furnace design meets all the requirements for conducting the proposed coarsening experiments, and its only shortcoming is its relatively large outer diameter, which limits the size of the induction coils and hence the filling factor for the induction measurements.

The design and construction of the bridge circuit for implementing the measurement of has not been so successful. The coils utilized to date in the bridge circuit provide an output voltage from balance (about 40 nV) of only ~300 nV on insertion of a rod of pure Al, 2.7 mm in diameter and 15 mm long, these figures pertaining to an input signal of 0.5 V at 20 kHz. The noise level of the circuit is 10 to 15 nV, so the sensitivity needed for performing the experiments on coarsening has not yet been achieved. Experiments using different frequencies have not improved the sensitivity or the S/N ratio of the circuit. Possible improvements involve reducing the size of the furnace/water-cooling assembly to increase the filling factor of the induction coils, and reconfiguring the coils.